

An Application of the
Multi-Mission Earth Entry Vehicle :
Galahad – An Asteroid Sample Return Mission

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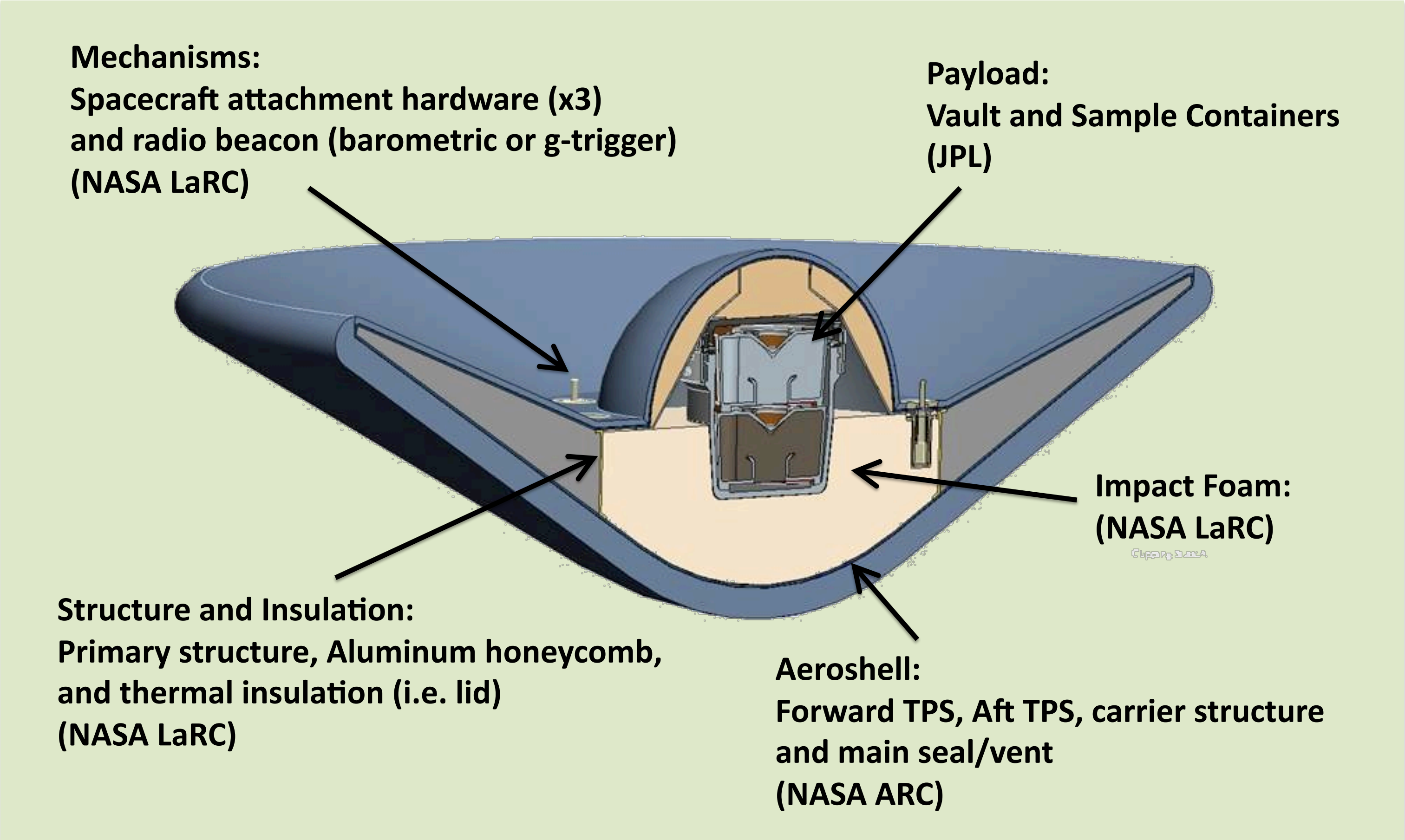
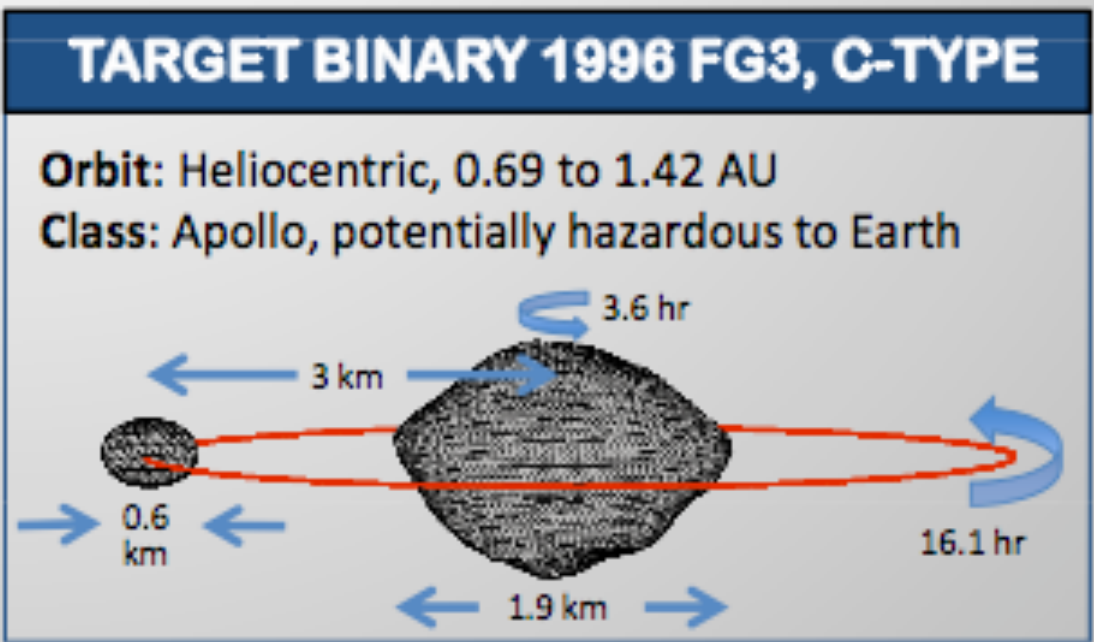
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20 April 2009: the National Aeronautics and Space Administration (NASA) released an Announcement of Opportunity for the 3rd New Frontiers mission. Galahad, an asteroid sample return mission, was proposed for Step 1.

SCIENCE GOALS	MISSION TEAM
Galahad calls for the return of samples from the organic-rich <i>binary</i> Near-Earth Asteroid 1996 FG3 to: <ul style="list-style-type: none">Explore diverse origins of planetary materials and initial stages of habitable planet formation;Determine the inventories of organics and volatiles, especially water, in a primitive asteroid;Understand the population of asteroids near the Earth	<ul style="list-style-type: none">PI : Andrew Cheng (JHU/APL)JPL : Galahad Project Management, system engineering, project mission assurance, Sample Transfer & Entry, Touch and Go, E/PO, mission design and mission operationsJHU/APL : Spacecraft, flight system mission assurance, payload, I&T and mission operationsLaRC/ARC : Earth Entry VehicleCSA : Robotic ArmsJSC : Curation Facility
MISSION OVERVIEW	
<ul style="list-style-type: none">Collect two samples from distinct sitesReturn samples to Earth – landing in UTTR – curation at JSCGlobally map both primary and secondary members of 1996 FG3 binary in monochrome, color, and near-IRVenus gravity assist trajectories to asteroid rendezvous and for Earth returnIntermediate class, low performance range launch vehicle with 4m fairing (Atlas V 401 or equivalent)Launch Period : 5-25 March 2018Return to Earth : 26 March 2024	



GALAHAD EEV OVERVIEW

Vehicle diameter :	1.12 m
Forebody shape :	60° half-angle sphere cone
Max. expected entry mass :	43.5 kg (includes 7.2 kg payload and 4.2 kg sample)
Max. expected Ballistic Coefficient :	60.5 kg/m²
Forebody TPS material :	unipiece PICA (Stardust heritage)
Aftbody TPS material :	Acusil II (heritage from U.S. DoD entry bodies, MSL)
Structure (primary and TPS carrier) :	isotropic graphite laminate
Impact foam :	ROHACELL® 200WF
Thermal design :	temperature at interior surface of the sample container never exceeds 45°C during entry or after landing

GALAHAD EEV / MMEEV VALIDATION
(nominal entry; 1.12 m diameter with 11.4 kg payload)

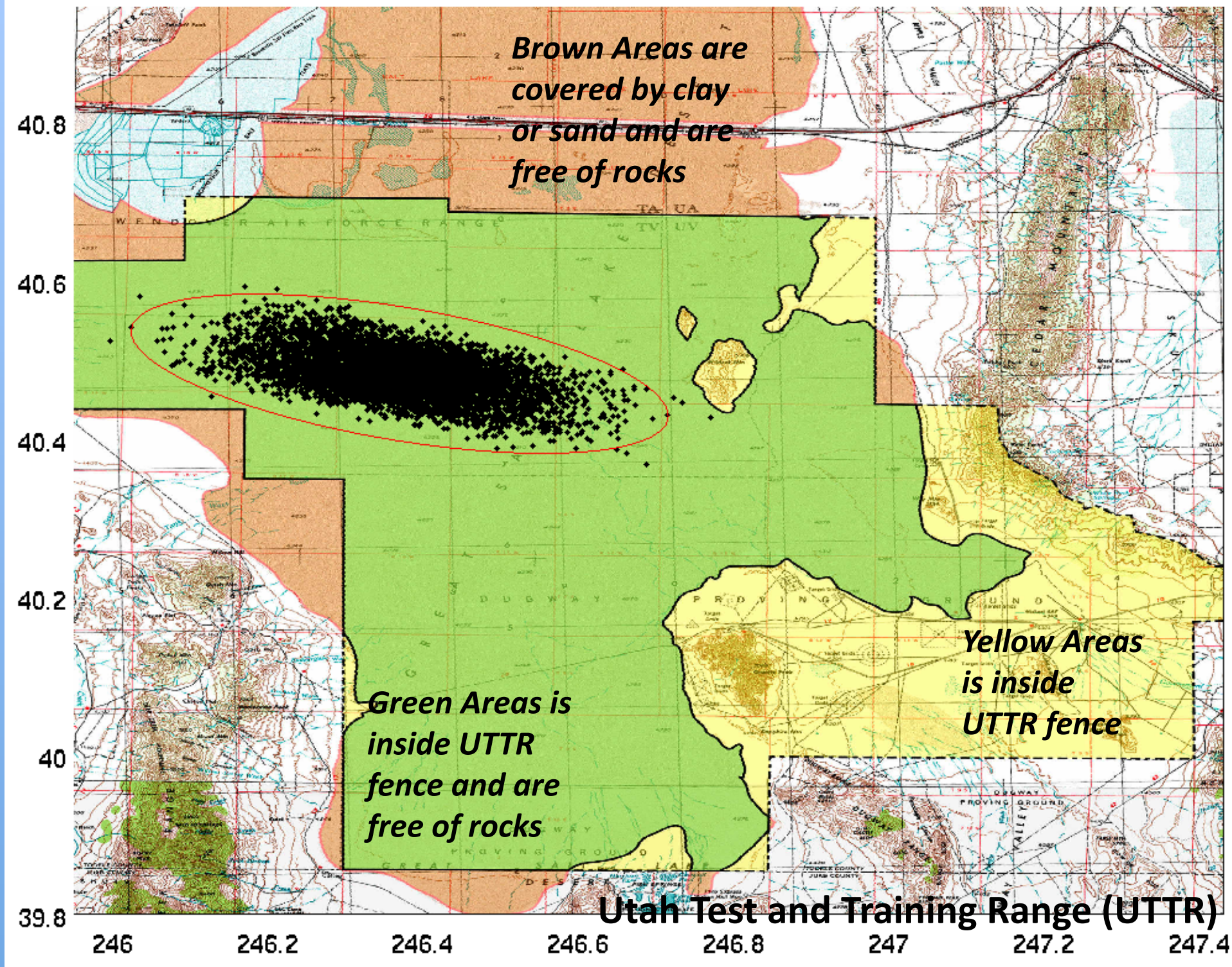
Parameter	Galahad	MMEEV	difference
Total entry mass (kg)	43.5	37.9	- 12.8 %
Maximum entry load (g's)	33.9	34.6	+ 2.1 %
Peak total heating (W/cm2)	400	373	- 6.9 %
Total heat load (kJ/cm2)	11.2	10.3	- 7.7 %
PICA thickness (cm)	2.3	3.3	+ 45.3 %*
Time of flight: entry to impact (sec)	595	629	+ 5.7 %
Impact velocity (m/s)	31.0	28.9	- 6.7 %
Impact load (G's) assuming all penetration	470	400	- 17.5 %
Impact stroke (cm) assuming 1500 G's all crush	3.4	3.1	- 8.8 %

* MMEEV TPS thickness estimate uses conservative (adiabatic) boundary condition; Galahad designed to insulating carrier structure.

The Galahad Earth Entry Vehicle (EEV) design is based on the Multi-Mission Earth Entry Vehicle (MMEEV) concept, which :

- was first introduced at IPPW-6 (Atlanta, GA) in 2008.
- is directed by NASA’s In-Space Propulsion Technology Program.
- is based on the Mars Sample Return (MSR) EEV design, which due to planetary protection requirements, is designed to be the most reliable space vehicle ever flown.
- provides a logical foundation by which any sample return mission can build upon in optimizing an EEV design which meets their specific needs.
- preserves key design elements which lower risk.
 - “Chute-less” Design:
 - Reliability of parachutes and automated deployment systems ~10⁻³.
 - Parachute system adds mass and increases capsule ballistic coefficient.
 - Packaging of parachute system interferes with sample transfer.
 - Landing footprint is increased due to greater sensitivity to winds.
 - Requires power, sensors, flight computer, sensors, pyros, etc.
 - Aerodynamic stability :
 - Provides robust performance against a wide range of entry condition dispersions, as well as atmospheric uncertainties.
 - Extensive aerodynamic database development and testing has been compiled for the 60° sphere-cone forebody shape.
 - Aftbody shape provides for hypersonic re-orientation capability, even when spin-stabilized 180° backwards or tumbling.
- provides a common platform by which key technologies can be identified, designed, developed and flight proven prior to implementation on MSR, providing significant risk and development cost reductions to any sample return mission.

GALAHAD 6DOF ENTRY MONTE CARLO ANALYSES



Parameter	Units	Mean	3σ
Entry Flight Path Angle*	deg	-7.8	0.07
Entry Velocity*	km/s	11.9	0.13
Peak Total Heating	W/cm²	431	32
Total Heat Load	kJ/cm²	10.8	0.7
Impact Velocity	m/s	31.4	2.6
Landing Footprint (max sample)	km	43 x 12 km	3σ

* planet relative

